

PAPER • OPEN ACCESS

## Durability increase of mining dump trucks through the use of protective coatings of the body

To cite this article: Y A Lagunova *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **862** 032029

View the [article online](#) for updates and enhancements.



**LIVE AWARDS AND SPECIAL EVENTS**

**PLENARY LECTURE:**  
"Perovskite Solar Cells: Past 10 Years and Next 10 Years" with *Nam-Gyu Park*

**LEGENDS OF BATTERY SCIENCE:**  
A Celebration with *M. Stanley Whittingham* and *Akira Yoshino*

**PRiME 2020 • October 4-9, 2020**  
*Hosted daily: 2000h ET & 0900h JST/KST*

**PRiME<sup>TM</sup>**  
PACIFIC RIM MEETING  
ON ELECTROCHEMICAL  
AND SOLID STATE SCIENCE  
**2020**

**ATTENDEES  
REGISTER FOR FREE ▶**

The banner features several circular icons: a green 'e' logo, a group of people, a gold medal, and a portrait of a man. It also includes a small circular logo for the Electrochemical Society.

## Durability increase of mining dump trucks through the use of protective coatings of the body

Y A Lagunova<sup>1,2</sup>, S A Khoroshavin<sup>1,2</sup> and A E Kalyanov<sup>2</sup>

<sup>1</sup>Ural Federal University named after the first President of Russia B.N. Yeltsin, 19 Mira street, Ekaterinburg, 620002, Russia

<sup>2</sup>Ural State Mining University, 30 Kuibyshev street, Ekaterinburg, 620144, Russia

E-mail: oldim96@mail.ru

**Abstract.** The share of trucking in the total cost of open-cast mining is 50% or more. Therefore, reducing transportation costs is one of the tasks of increasing the technical and economic indicators of an open development method, which is an urgent task. Performance dump truck is estimated either by the volume of transported rock mass (in cubic meter or tons), or the value of cargo turnover (ton-kilometers). However, these indicators do not take into account the percentage of adhering rock that is transported uselessly and reduces productivity. The paper proposes methods for protecting the body of a mining dump truck from clay rocks adhering. Detail the method of protection with the help of vibration using metal structure is considered. A mathematical model of the stress-strain state of a two-layer beam is proposed. The dependence of the stress in the body on the stiffness of the elastic supports and impact energy when using a rubber lining is shown.

In 2013, the largest in the history of the world automotive industry BelAZ -75710 mining dump truck with a lifting capacity of 450 tons was created. This giant was the result of an innovative technical policy of the enterprise, focused on the production of efficient equipment that meets consumer needs.

Popular models of BelAZ mining dump trucks:

- BelAZ -75453 with a loading capacity of 45 tons with an engine with a capacity of 600 horsepower with a hydromechanical transmission and an automatic control;
- BelAZ -75602 with a carrying capacity of 360 tons with an engine with a power of 3750 horsepower and an electromechanical transmission of alternating current.

On the basis of the BelAZ-75191 dump truck manufactured earlier, samples of BelAZ -75195 diesel-trolley cars were created, on which two TT-1 current collectors in the form of a pantograph and a rod type are additionally installed. The diesel power is 860 kW, the GPA-600 traction generator with a capacity of 630 kW, the voltage in the contact network is 820 V. Tests have shown the effectiveness of diesel-trolleys cars especially in deep quarries, since they operate from the contact network on steep climbs, which positively affects ecological situation of the region.

In 2013, at the BelAZ test site, the first public presentation of the capabilities of the BelAZ-75131 robotic mining dump truck with a lifting capacity of 130 tons and new developments by the company's



specialists - mining dump trucks with a lifting capacity of 90 tons with an electromechanical transmission took place.

Today, BelAZ-HOLDING, which has combined the production potential of five industrial enterprises of the Republic of Belarus, is implementing new technological and design ideas that contribute to improving the operational characteristics of the quarry equipment produced.

One of the problems faced by manufacturers of heavy-duty mining dump trucks is the adhering of material in the dump truck body when transporting frozen clay.

The freezing of soil on the surface of the body of a mining truck in the winter (according to estimates [1] - an average of up to 2 cubic meters per flight) leads to a significant cost overrun of financial, material and labor resources. Reducing these losses is an important task.

The share of trucking in the total cost of open-cast mining is 50% or more. Therefore, reducing transportation costs is one of the tasks of increasing the technical and economic indicators of an open development method. Vehicle performance is estimated either by the volume of transported rock mass (in cubic meter or tons), or the value of cargo turnover (ton-kilometers). However, these indicators do not take into account what percentage of adhering rock is transported uselessly and reduces productivity.

There are many options for solving the problem of sticking rocks in the body. This includes treating the body with salt, applying a special film, coating the dump truck body with special OKUSLIDE material from OKULEN, applying an epoxy or emulsion composition, using water lubricant, a special lining complex, gumming the dump truck body, heating the dump truck body with exhaust gases from the engine (which is very environmentally harmful), application cleaning ultrasound, cleaning dump truck body knife since the rope mechanism.

A promising way is the destruction of adhesive bonds between the lining of a steel dump truck body and frozen ground by excitation vibrations of body elements.

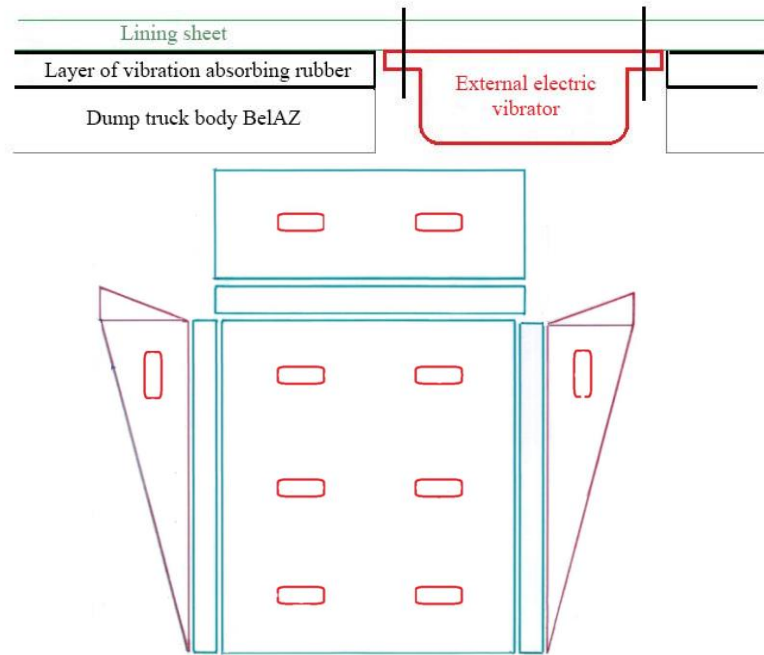
In our works [1, 2, 3, 4], it was proposed to use a combined version using a lining sheet, a layer of vibration-absorbing rubber and an external electric micro-vibrator (figure 1).

On the surface of the internal parts of the dump truck body (bottom, sides, rear wall), apply the necessary layer of vibration absorbing rubber. In turn, lining sheets are laid on it, fastening them with a bolted connection to the dump truck body. Electrical external micro-vibrators are installed on the lining sheets, having previously prepared a place in the form of a "window". "Window" cut in the wall of the body. The micro-vibrator is connected to the lining sheets with a special bolted connection.

We examined the influence of vibration characteristics on the strength of the steel-ground system. Theoretical studies of the effect of vibration on cohesive rocks when they freeze on the body surface of a mining dump truck by using a model of a two-layer beam are carried out. The use of electric vibration motors will allow you to effectively deal with sticking by means of vibrations and transferring them to coherent rock through the working surface of the body. Upon reaching resonance between the cohesive rocks and the working surface, detachment occurs, thereby, the working surface of the body is completely cleaned.

Assume that the soil is evenly distributed along the bottom. We consider the lining of the underbody with frozen ground as a two-layer plate pivotally supported at the edges and loaded with a uniformly distributed load. Under such loading, the two-layer plate is in cylindrical bending. It is necessary to cut a strip of single width from plate with two straight lines and it is necessary to consider the stress-strain state of the bilayer beam.

We assume that the beam layers are linearly elastic. Between themselves, the layers are continuously connected by normal connections and tangents to the axis of the beam, connections. They hold the layers of the beam from mutual displacement in the direction transverse to the axis. Tangent bonds (shear), which prevent the mutual shear of the layers in the direction of the axis, are considered linearly elastic. The linear tangential force in the seam [N / m] and the mutual displacement of adjacent layers [m] are subject to the law



**Figure 1.** Vibration protection of the body.

$$q = k\Delta, \quad (1)$$

where  $k$  - is the stiffness of the shear bonds,  $\text{N}\cdot\text{m}^2$ .

The calculation of the  $n$ -layer beam is given in [2, Chapter 14, p. 467 - 470].

Determining the forces acting in the  $n$ -seams is a statically indeterminate degree task  $n$ . We remove the shear bonds in each seam and replace them with linear tangential forces, where  $i=1,2,\dots, n$  - is the seam number. An unknown force is the resultant of the tangential forces ( $x$ ) acting on one side of the section. The unknown force  $T_i(x)$  and linear tangential forces  $q_i(x)$  are related by the relation

$$T_i(x) = T_i(0) + \int_0^x q_i(\xi) d\xi \quad \text{or} \quad T_i'(x) = q_i(x). \quad (2)$$

The constant  $T_i(0)$  is determined from the boundary conditions at the end  $i$  of the seam.

The total bending moment in the section, caused by the action of an external load,  $M^o(x)$  is distributed between the layers in proportion to their stiffness.

$$M_i(x) = E_i J_i / \sum_{k=1}^n E_k J_k M^o(x). \quad (3)$$

Having expressed the amount of shear in section  $x$  of seam number  $i$  through external forces and extra unknowns, we write down the differential equation for each seam.

$$T_i''(x) - \kappa \sum_{k=1}^n T_k(x) \delta_{ik} = \Delta_{ip} \kappa_i \quad (4)$$

The load coefficients of the system of equations of the method of forces are equal

$$\Delta_{ip} = -N_i^0 / E_i F_i + N_{i+1}^0 / E_{i+1} F_{i+1} - M^o(x) / \sum_{k=1}^n E_k J_k. \quad (5)$$

where  $N_i^0$  is the external axial load applied to the layer  $i$ .

We write the coefficient matrix for unknown systems of canonical equations of the force method. The members on the main diagonal are found by the formula

$$\delta_{ii} = 1/E_i F_i + 1/E_{i+1} F_{i+1} + h_i^2 / \sum_{k=1}^n E_k J_k. \quad (6)$$

The elements of the diagonal, that lies above the main, are equal

$$\delta_{i-1,i} = -1/E_i F_i + h_{i-1} h_i / \sum_{k=1}^n E_k J_k \quad (7)$$

The elements of the diagonal, which lies under the main, are equal

$$\delta_{i+1,i} = -1/E_{i+1} F_{i+1} + h_i h_{i+1} / \sum_{k=1}^n E_k J_k \quad (8)$$

The remaining members of the coefficient matrix at unknowns are equal

$$\delta_{ik} = h_i h_k / \sum_{j=1}^n E_j J_j \quad \text{at } |i - k| > 2. \quad (9)$$

The general solution of the system [4] has the form

$$T_i(x) = \sum_{k=1}^n \beta_{ik} \bar{T}_k(x) \quad (10)$$

where  $\beta_{ik}$  are the constants ( $i, k = 1, 2, \dots, n$ );  $\bar{T}_k(x)$  - eigenfunctions of the form

$$\bar{T}_k(x) = A_k \operatorname{sh} \lambda_k x + B_k \operatorname{ch} \lambda_k x; \quad (11)$$

$\lambda_k$  - the roots of *the* characteristic equation:

$$\begin{vmatrix} \kappa_1 \delta_{11} - \lambda^2 & \kappa_1 \delta_{12} & \dots & \kappa_1 \delta_{1n} \\ \kappa_2 \delta_{21} & \kappa_2 \delta_{22} - \lambda^2 & \dots & \kappa_2 \delta_{2n} \\ \dots & \dots & \dots & \dots \\ \kappa_n \delta_{n1} & \kappa_n \delta_{n2} & \dots & \kappa_n \delta_{nn} - \lambda^2 \end{vmatrix} = 0. \quad (12)$$

Constants  $A_k, B_k$  are found from the boundary conditions at the ends of the k seam: if there are no obstacles to mutual shear at the end of the seam, then  $A_k = B_k = 0$ ; with a hard shear obstacle, the constants are found from (2) written for the seam.

A particular solution to the system of differential equations (4) is written in an integral form similar to the Duhamel integral in the theory of oscillations [3]

$$T_i^*(x) = \sum_{k=1}^n \kappa_k / \lambda_k \int_0^x \Delta_{kp}(\xi) \operatorname{sh} \lambda_k (x - \xi) d\xi \quad (13)$$

Adding formulas (10) and (13) we find the unknowns  $T_i(x)$ . Further determine the axial forces acting in each layer

$$N_i(x) = T_i + N_i^0 - T_{i-1} \quad (14)$$

The bending moments in the layers are found by the expression

$$M_i(x) = E_i J_i / \sum_{k=1}^n E_k J_k (M^0(x) - \sum_{i=1}^n T_i h_i) \quad (15)$$

For a two-layer beam, the task once becomes statically indefinable. We arrive at a linear differential equation of the second order

$$T'' - \kappa \delta T = \kappa \Delta \quad (16)$$

The coefficient with the unknown and the cargo coefficient are equal

$$\delta = 1/E_1 F_1 + 1/E_2 F_2 + h^2 / (E_1 J_1 + E_2 J_2) \quad (17)$$

$$\Delta = -N_1^0 / E_1 F_1 + N_2^0 / E_2 F_2 - M^0 h / (E_1 J_1 + E_2 J_2) \quad (18)$$

The characteristic equation (12) takes the form  $\lambda^2 = \kappa\delta$ .

Extra unknown equals

$$T(x) = A \operatorname{sh} \lambda x + B \operatorname{ch} \lambda x + \kappa/\lambda \int_0^x \Delta(\xi) \operatorname{sh} \lambda(x - \xi) d\xi \quad (19)$$

Differentiating  $T(x)$ , we find linear tangential force  $q(x)$  in the seam

$$q(x) = \lambda A \operatorname{sh} \lambda x + \lambda B \operatorname{ch} \lambda x + \kappa \int_0^x \Delta(\xi) \operatorname{sh} \lambda(x - \xi) d\xi \quad (20)$$

The distribution of linear shear forces will be used to determine the location of the vibrators.

If the external axial forces  $N_1^0 = 0, N_2^0 = 0$ , then the elastic line of the two-layer beam is determined by integrating the fourth-order differential equation

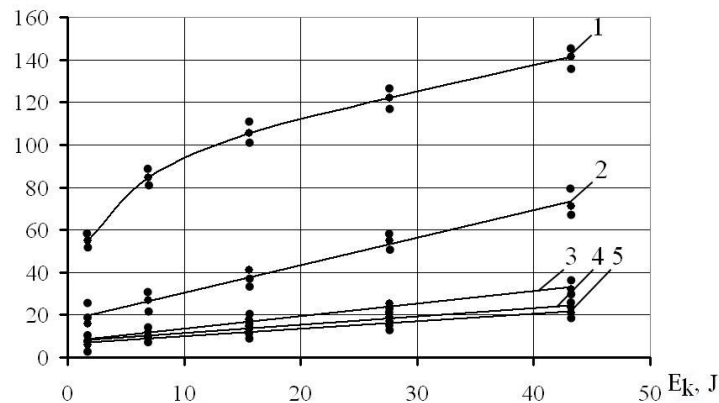
$$v^{IV} - \kappa\delta v'' = (-M^{o''} + \kappa\delta M^o) / (E_1 J_1 + E_2 J_2) \quad (21)$$

The regression dependence of the stress in the body on the stiffness of the elastic supports and impact energy was revealed [5-11], while lining the body with rubber the following dependence was obtained:

$$\sigma_p = -84,267 + 19,827E_k - 4,89h_p + 0,041E_r^2 + 0,146h_p^2 - 0,051E_k h_p - 0,329E_r E_k$$

where  $E_r$  is Shore rubber hardness;  $h_p$  - rubber thickness, mm;

$\sigma$ , MPa



**Figure 2.** The dependence of the stress in the body  $\sigma$  on the impact energy  $E_k$  at different thicknesses of the rubber layer  $h_p$ : 1 - without lining; 2  $h_p = 6$  mm; 3  $h_p = 12$  mm; 4  $h_p = 18$  mm; 5  $h_p = 24$  mm.

Conclusion: the determination of the elastic line  $v(x)$  will allow you to correctly select the amplitude-frequency characteristics of the excited oscillations.

## References

- [1] Demchenko I I 1992 *The search for methods and means of combating the buildup and freezing of the rock mass in industrial vehicles in the context of KATEK* (Irkutsk) p 32
- [2] *Strength, stability, fluctuations* vol 1 ed I A Birger *et al* 1968 (Moscow: Engineering) p 831
- [3] Panovko Y G 1967 *Fundamentals of the applied theory of elastic vibrations* (Moscow: Engineering) p 316
- [4] Zolkin A P, Lagunova Yu A and Semenov A V 2019 Using a model of a two-layer beam for the design of anti-freezing tools in the bodies of mining dump trucks *Technological equipment for the mining and oil and gas industries* **17** 489
- [5] Belyushin D V and Lagunova Yu A 2016 Regression analysis of the dependence of the indentation force on the area and hardness of the lining of vibrator machines *GIAB* **7** 5-16
- [6] Belyushin D V and Lagunova Yu A 2017 Analysis of experimental data on the impact interaction

- of the working surfaces of vibratory machines with rock. *Mountain Journal* **6** 62-7
- [7] Roland C M 2009 Vagaries of elastomer service life prediction. *Plastics, Rubber and Composites* **38(8)** 349-54
- [8] Kannan G K, Gaikwad L V, Nirmala L and Kumar N C 2010 Thermal ageing studies of bromo-butyl rubber used in NBC personal protective equipment. *Journal of Scientific & Industrial Research* **69** 841-9
- [9] Coveney V A 2006 *Elastomers and Components. Service Life Prediction - Progress and Challenges* (Cambridge: Woodhead Publishing Limited) p 238
- [10] ASTM D 412-06a 2007 *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension* (Washington : American Society for Testing and Materials) p 14
- [11] Al-Juothry S A 2014 The Influence Surface Area and Structure of Particles Carbon Black on Cure Characteristics and Mechanical Properties of Natural Rubber *International Journal of Advanced Research in Engineering and Technology* **5** 149-59